KUBIK: OPEN BUILDING APPROACH FOR THE CONSTRUCTION OF AN UNIQUE EXPERIMENTAL FACILITY AIMED TO IMPROVE ENERGY EFFICIENCY IN BUILDINGS

José A. Chica, Inés Apraiz, Peru Elguezabal,
Marc O. Rrips, Victor Sánchez & Borja Tellado

Abstract
KUBIK is aimed to the development of new concepts, products and services to improve the energy efficiency of buildings. The main characteristic of KUBIK is the capability to built realistic scenarios to analyse the energy efficiency obtained from the holistic interaction of the constructive solution for the envelope, the intelligent management of the climatisation and lighting systems and the supply from renewable energy sources.

The R&D infrastructure consists of a building able to provide up to 500 m2 distributed in an underground floor, a ground floor and up to two storeys; the main dimensions are 10,00 m. width x 10,00 m. length x 10,00 meter high (plus and underground floor 3,00 m. depth). The supply of energy is based on the combination of conventional and renewable energy (geothermic, solar and wind). In addition, the building is equipped with a monitoring and control system which provides the necessary information for the R&D activities.

KUBIK´s main structure provides an experimental, adaptable and reconfigurable infrastructure to create the indoor environments to analyse and to allow the assembly of the constructive solutions for the envelope, floors and partitions which performance must to be assessed under realistic conditions.

Keywords: *Industrialised product development, Reconfigurable, Disassembly, Energy Efficiency, R&D Infrastructure.*

INTRODUCTION

The design of KUBIK is based on an industrialised approach to achieve a flexible and adaptable experimental facility, an open building-system, to evaluate and optimise new construction components and solutions, systems and services for the improvement of building energy efficiency.

The Open Building concept is not new and the main principles have been established by Habraken (Habraken, 1998):

- Distinct Levels of intervention in the built environment, such as those represented by 'support' and 'infill', or by urban design and architecture.
- Users / inhabitants may make design decisions as well.
- Designing is a process with multiple participants also including different kinds of professionals.
- The interface between technical systems allows the replacement of one system with another performing the same function.
- The built environment is in constant transformation and change.
- The built environment is the product of an ongoing, never ending, design process in which environment transforms part by part.

However, there is still a need to disseminate and to train the stakeholders of the construction sector to fully understand and to implement the Open building concept in our buildings and built environment (Open House International, 2006), (Kendall, 2008).

On other hand, one key innovation regarding the implementation of the Open Building concept is the industrialisation of it. The industrialisation of the open building concept has been dealt at concept level and the state of the art introduced by the CIB (International Council for Research and Innovation in Building and Construction) (Sarja, 1998). And, more recently, has been a hot topic for R&D in Europe (Manubuild, 2009).

To finalise this introduction of the issues that have influenced the design of the research facility, KUBIK, it is compulsory to address the current envi-

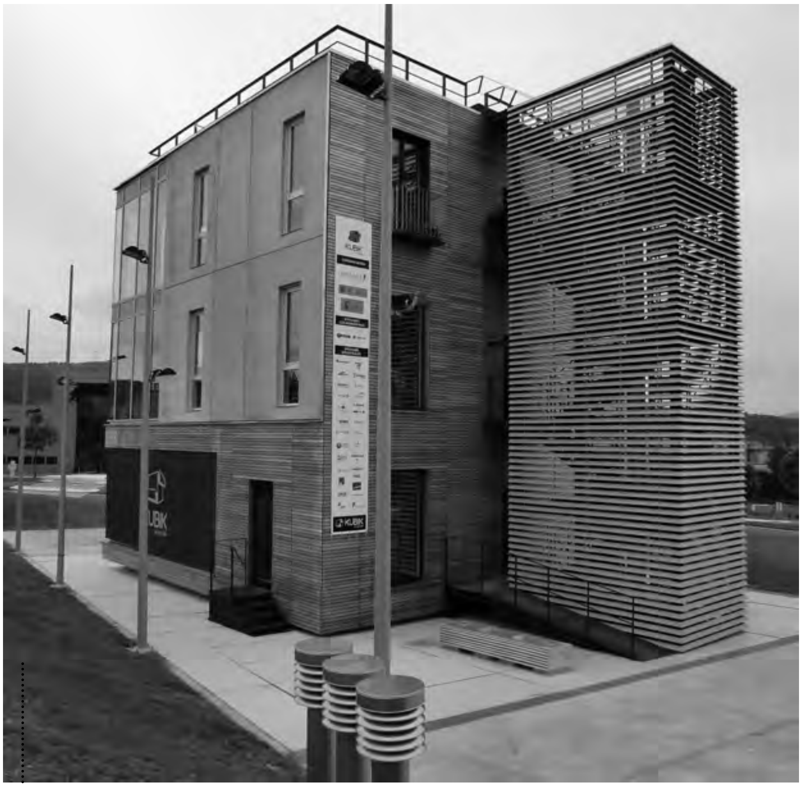

Figure 1. *Current envelope in KUBIK*

ronmental concern that affects the building industry, mainly driven by the energy performance of the built environment and the new European Energy Performance Directive in force (EPBD, 2008) and the R&D initiative lead by the European construction sector to meet this challenge, the Energy Efficient building Joint Technology Initiative (E2B JTI, 2010).

As summary, KUBIK provides the needed support to improve the energy performance at building level, as requested by the EPBD, and in a comprehensive way, the envelop, the demand and energy generation, and based on industrialised construction systems.

KUBIK AIMS AND DESCRIPTION

The "openness" of KUBIK

Although it is necessary to acknowledge that does exist a previous similar facility by the Fraunhofer Institute of Building Physics in Germany (VERU, 2005), whose team has collaborated with Tecnalia in KUBIK, KUBIK offers new characteristics that make it a distinctive and unique world-class experimental R&D infrastructure designed for the evaluation and optimization of new construction components and solutions, systems and services for the improvement of building energy efficiency under real conditions.

The main distinctive feature of KUBIK is its capacity to create realistic scenarios, its "openness", to perform experimental research with regard the building energy efficiency resulting from the interaction of the constructive solutions, the intelligent management of air-conditioning and lighting systems and the non-renewable and renewable combinations of energy supplies. And, in addition, is focused in the development of industrialised components for the implementation of the open building concept, see Fig. 1.

The infrastructure encloses a maximum of 500 m2 distributed over a basement, a ground floor and a further two floor levels; the main dimensions are 10,00 m. width x 10,00 m. length x 10,00 meter high (plus and underground floor 3,00 m. depth). The supply of energy is based on the combination of conventional and renewable energies (geothermic, solar and wind power). Finally, the building is equipped with a monitoring and control system that provides the necessary information for the development of R&D. The building is totally demountable and allows reconfiguration of the scenarios at construction level, by exchanging the components of the envelope, the roof, the floors and the partitions.

The "openness" of KUBIK has been implemented in all the sub-systems of the building:

- the structure,
- the envelope,
- the partitions, actually, only dry construction systems are used,
- the services, energy and IT related, and
- the equipment, mainly climatisation and energy intelligent management

The "openness" of all these sub-system will be shown in the following sections of this paper

Experimental capabilities of KUBIK

KUBIK enables the evaluation of energy performance, acoustic performance and air tightness evaluation of the scenarios built, see Fig. 2, taking into account the holistic interaction of the constructive solution for the envelope, the intelligent management of the climatisation and lighting systems and the supply from non-renewable and renewable energy sources.

The main aim of KUBIK is to provide a better understanding of the performance at room or at building level, acknowledging the traditional laboratories as the better for the characterisation at component level according international agreed standards.

KUBIK has an advanced monitoring system, equipped with over 400 sensors that records conditions inside and outside the experimental facility, climatic conditions. Researchers and customers have access via the Internet to measurements being taken in the scenarios where the performance of the products and systems under development are evaluated. In addition, the monitoring system is integrated into an Intelligent Energy Management System which optimises the energy consumption of the building. The experimentally-obtained results enable diagnoses and proposals for potential product improvements to be made.

It is important to note the contribution of KUBIK for the activities related to the new product development for buildings. Currently, the technical

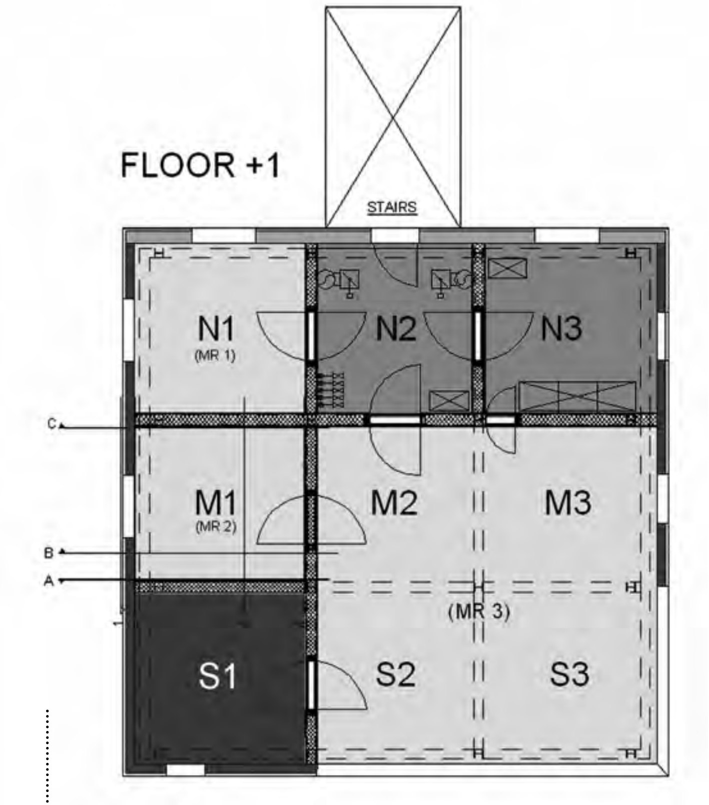

Figure 2. *Plan view showing the available layouts with independent climatisation systems*

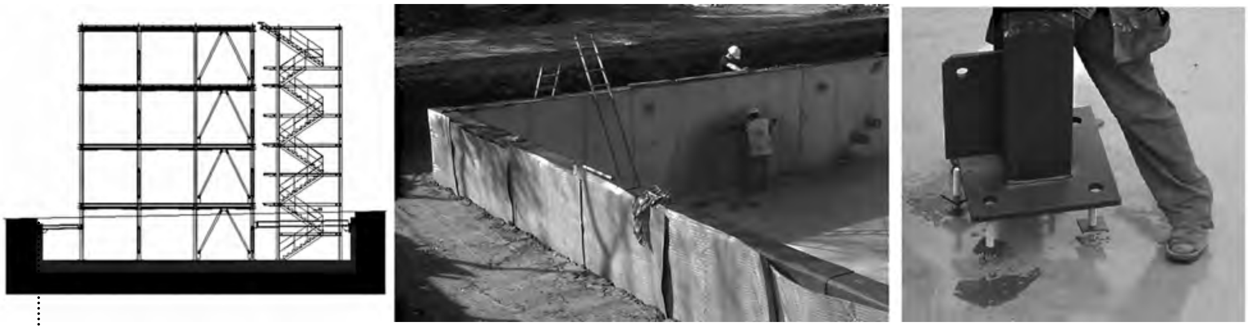

Figure 3. Section of the basement "Plug" with the steel structure (left) Underground floor with geothermal installation and energy supply and IT connections (middle) &, Steel columns anchored to the foundation slab with bolted (demountable) base plates (right)

development of a product begins with the numerical analysis and simulation of the product, carried out in a virtual scenario. The product is then tested in a laboratory in accordance with standardised procedures, and is finally launched on the market.

KUBIK offers and intermediate step that allows to evaluate the products performance in realistic conditions. This speeds up the product development and reduces the risk of malfunction of highly innovative products or products without previous experiences on the market place.

The aim of this experimental facility is to offer a flexible infrastructure able to build realistic scenarios with different building components and systems, for that is compulsory to make possible the assembly and disassembly of them. This permits not only in service performance assessment but also help to develop and to evaluate assembly and erection procedures.

STRUCTURAL SYSTEM, SUPPORT STRUCTURE

Foundation and underground floor

The foundation, an underground slab and walls, and hereby the resulting underground floor are really the unique "not-open" sub-system of the building. The foundation is made of on-site reinforce concrete but with the innovation of the substitution of the stone aggregates by slag from electric arc furnace for steel manufacturing.

Although "not-open", the slab foundation provides the needed flexibility, "openness", to allow any lay-out of the steel structure columns. In addition, the underground floor is in concept a "plug" where the building takes the energy supplies, renewable and non-renewable, to run the scenarios as well as the data connectivity for the IT systems and intelligent management, see Fig. 3.

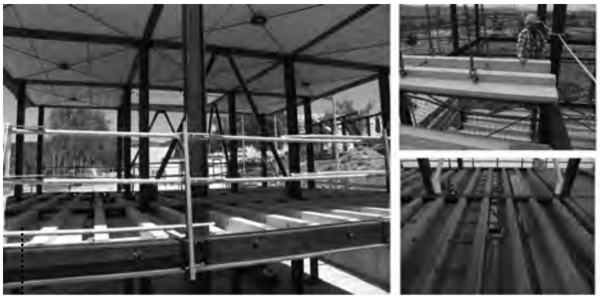

Figure 4. Demountable, floor by floor, steel structure and precast concrete slab. The steel beams and precast slabs allow building services integration..

Steel structure and precast concrete floors

The steel structure is made of standardised sections for the columns and fabricated sections for the beams; this special section allows the integration of the floor system and the building services.

The joints of steel structure are bolted and the bracing system includes "X" bracings in the floor to allow the use of demountable precast concrete slabs. The structure, columns, beams and floors allows its de-construction floor by floor level, see Fig 4.

As it is shown in the Figure 4, the service installations are integrated in the floor slabs, so they are accessible for repair and upgrading. Thanks to a complete demountable timber finishing, the accessibility is accomplished from the all the space being served by those installations, the room or

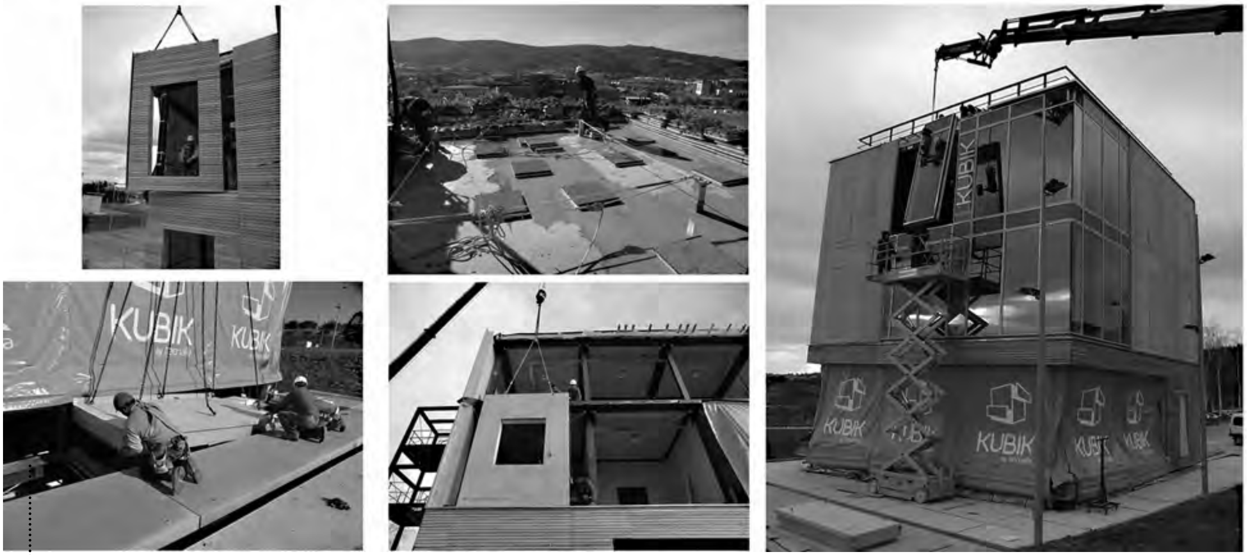

Figure 5. *Industrialised infill systems currently under study in KUBIK: (left to right and Top to bottom).1) Modular wooden ventilated façade system 2) Modular green roof system 3) Precast modular roof system for the underground floor. 4) Modular concrete sandwich panel 5) Modular curtain wall for PV integration*

combination of rooms for the analysed scenario.

ENVELOPE AND PARTITIONS, INFILL COMPONENTS

The special focus on the R&D activities on the improvement of the energy performance of buildings makes necessary the development of optimised solutions for the envelope taking a special attention, in the case of prefabricated or industrialised components, to the joints and connections to avoid thermal bridges, lost of continuity of the insulation of the envelope…

Currently, in KUBIK there are several solutions under study, see Fig. 5. This variety of solutions for envelopes allows analysing the real compatibility between components made of different materials, with different fabrication tolerances and different erection and joining technologies.

In fact, the keystone for a real open building implementation might be the possibility of having industrialised components available in the market with several "joining or interface standardised options" that could make possible the use of components from a variety of manufacturers, materials…And, in addition, the joints are really important to deal in detail how to assess the thermal and acoustic performance of the building but on other hand, they must allow the easy disassembly.

The roof and the façade of KUBIK are made of prefabricated and demountable components. So we refer them as infill systems because they can change when the rest of the infill or fit-out changes, e.g. the scenario (room surface, occupancy, partition walls and the envelope components), following the example of the NEXT 21 project. On other hand, the façade might acts as a support system to include several types of windows, glassing systems, finishing…

Regarding the internal partitions, light steel frames and timber frames it have been used to arrange the different rooms in each floor to create the "volume control" of each scenario in terms of energy and acoustic performance.

HEATING, VENTILATING AND AIR CONDITIONING SYSTEM (HVAC SYSTEM)

The primary function of the HVAC installation of KUBIK is to provide the energy necessary to keep the different measurement rooms, scenarios, of the infrastructure under controlled indoor conditions (temperature and humidity), as well as measuring the energy delivered to each measurement room to obtain the results to carry out the research regarding the components and/or systems under analysis.

Since the building has been conceived to enable the possibility of modifying the envelope

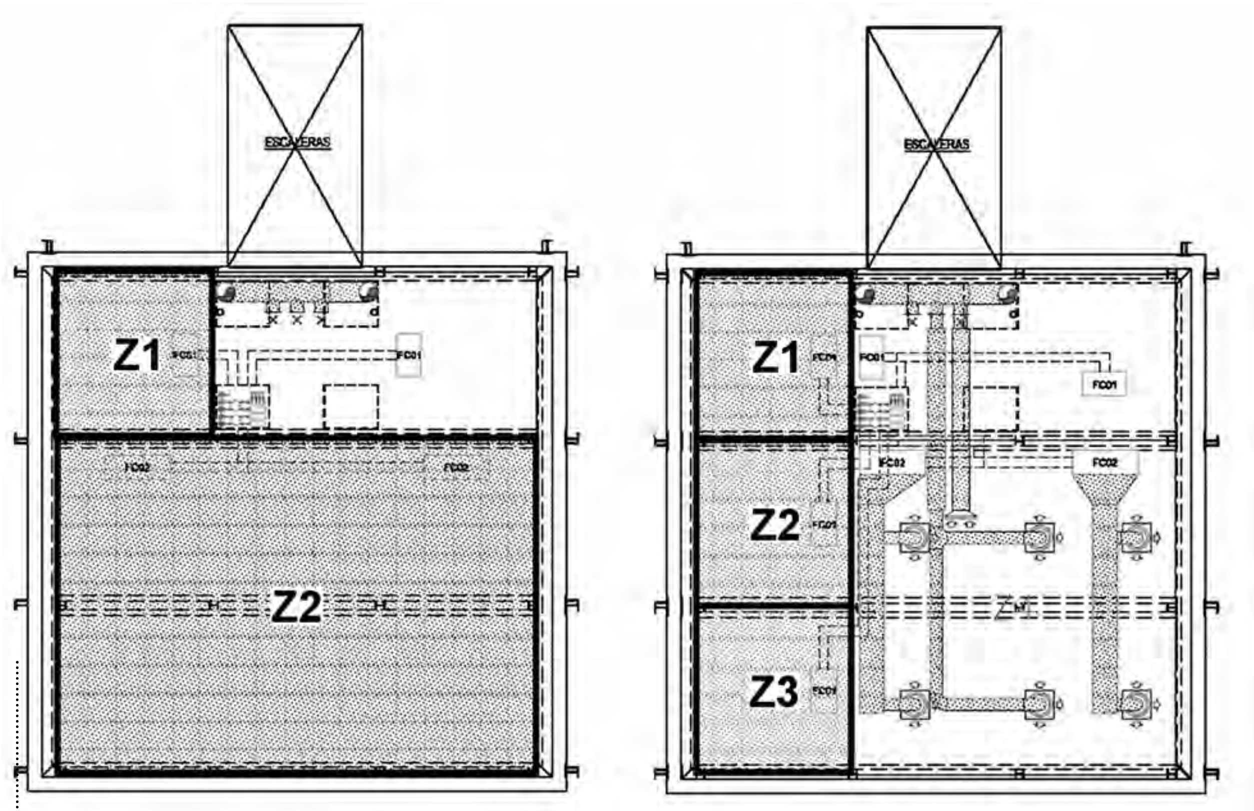

Figure 6. Thermal zones on the ground floor (left), Thermal zones on first and second floors (right) According current layout of KUBIK

and its floor layout, the HVAC system has been designed to support this feature:

- ability to satisfy thermal loads which may vary (especially for the cooling regime) within a wide range (25 -50 kW), and
- maximizing the ability of the distribution and the diffusion systems to adapt to variable floor layout.

Each of the 3 floors of the building can be divided into a maximum of 6 thermal zones, and if necessary, those zones can provide independent temperature setpoints and measured energy supply, see Fig. 6.

In addition, the entire HVAC installation have been designed so that its expansion through the integration of additional elements will be possible without the need to modify none of the main subsystems of the facility (generation, distribution, measurement and diffusion), beyond the minimum required adjustments.

For research purposes, KUBIK sums up to the conventional generation systems and air conditioning elements:

- Distributed electricity generation from renewable sources (photovoltaic and wind).
- A ground source heat pump, coupled to a heat exchanger with the surrounding ground (superficial) for water.
- A Canadian well, formed by a heat exchanger with the surrounding ground (superficial) to provide outdoor air for ventilation when the difference of outside air and ground temperatures is adequate.

The HVAC installation of air conditioning of KUBIK consists of an hydronic system, see Fig. 7, and a Variable Air Volume system (VAV), see Fig. 8. Both systems, will have independent distribution, measurement and diffusion subsystems. And for thermal energy generation, both systems will be fed by a common generation sub-system based on natural gas.

The air handling unit has been dimensioned to carry out the ventilation of the whole building or alternatively to reproduce on a single floor, the conditions of a building conditioned by a variable air volume system. It is possible to supply ventilation air

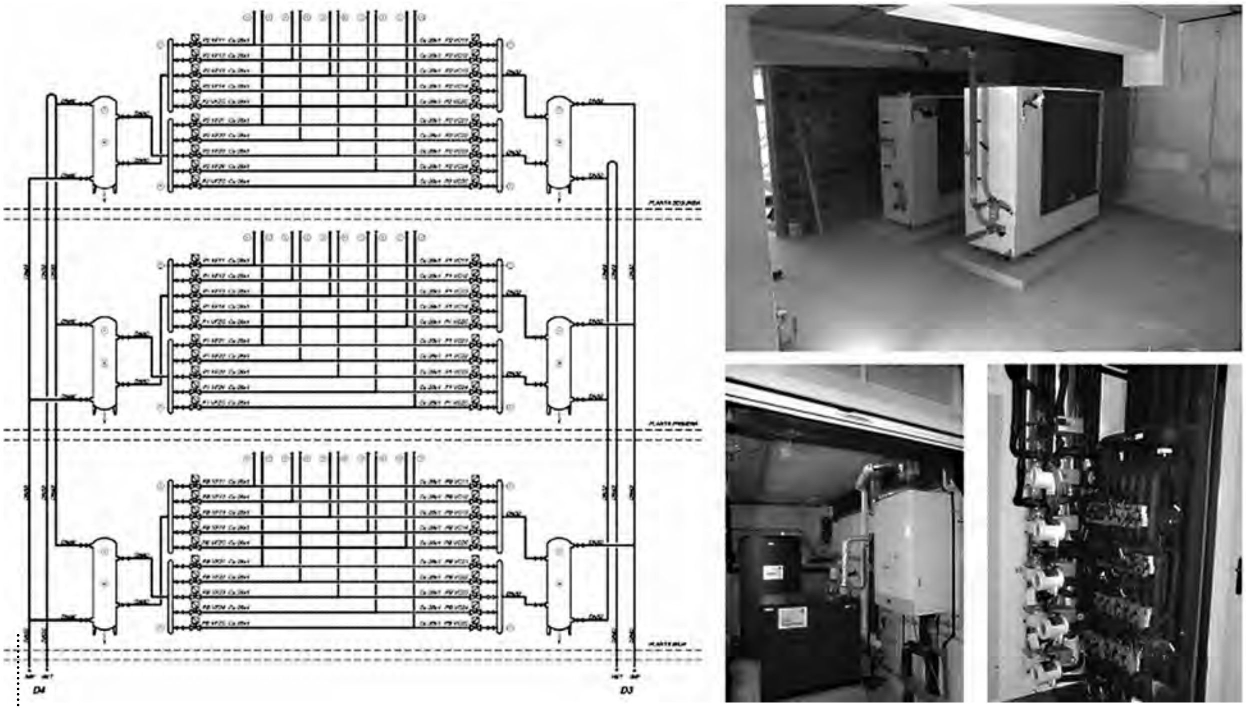

Figure 7. *Hydronic systems for the HVAC installation. Scheme(left), distribution pipes and equipments (right) related to thermal energy: natural gas micro CHP (12.5 kW of thermal power and 5.5 kW of electrical power), storage tank, condensing boiler and 2 air-condensed chillers 22 kW each.*

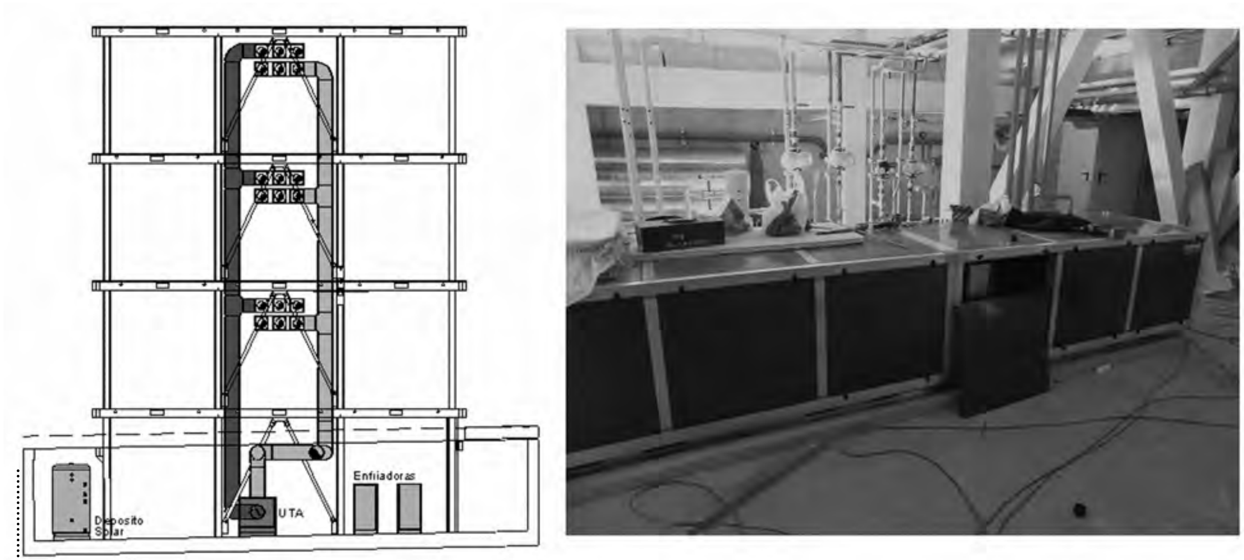

Figure 8. *Variable Air Volumen System (VAV) for the HVAC installation.Scheme(left); Variable flow air handling unit (right) (maximum flow of 2,500 m3 / h)*

up to 3 independent thermal zones per floor. The location of diffusers is optimized to maximize the capacity of the air system to accommodate changes in the thermal zoning of the different floors.

Summarizing, the HVAC system is in the Support or Base Building and the diffusers and other services such us electrical power, water… are placed integrated in the floor and ceiling of each room so we can consider that from this point the parts become infill elements...

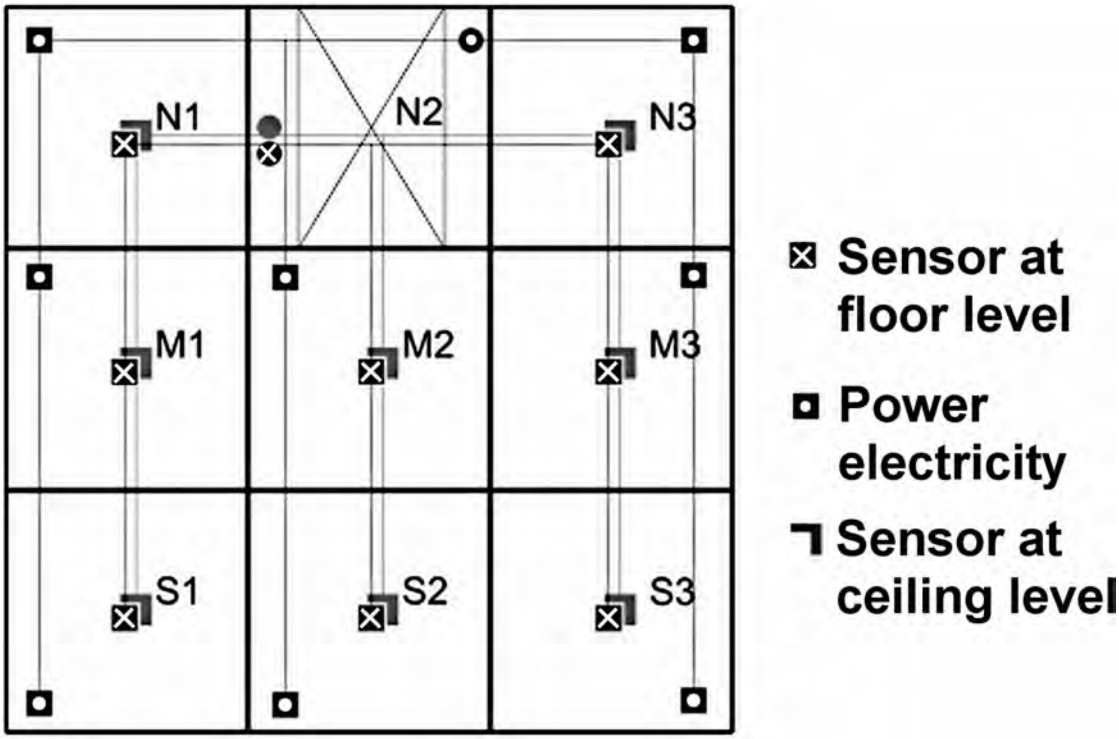

Figure 9. *Equipment by each individual measurement rooms. Blue boxes: sensor at floor level, Pink boxes: sensor at ceiling level & Brown boxes: power electricity. A floor integrated sensor box is showed in Fig.4*

MONITORING AND MANAGEMENT SYSTEM

At the end, all the flexibility required to KUBIK aims to provide a R&D infrastructure able to perform diverse scenarios and to capture the necessary information to carry out the analysis and assessments.

The infrastructure has up to seven individual measurement rooms; one control room and one service room per each of the three floors, see Fig. 9. It provides the possibility to combine some individual rooms into a unique measurement room if it is required by the experiment it and also allows to have all the three floors as a unique building, for example an specific office, school, etc….. This flexibility is possible thanks to the structural design and to the services design: each individual measurement room has the climatisation, power and data network that needs to build an scenario.

The Figure 9 shows the nine rooms of each floor with the electrical and data network: the individual measurement rooms are: N1, M1, M2, M3, S1, S2 and S3; the control room is N3 and the service room is N2. Figure 6 shows too an example of a possible layout of one floor: three individual measurement rooms (N1, M1 y S1) and one combined measurement room (a combination of M2, M3, S2, and S3) and their respective HVAC system.

The monitoring and management system is integrated in an intelligent energy system (IES) which optimizes the energy consumption of the building satisfying each measurement room needs. This system is in charge of data gathering and management tasks and to provide comprehensive information necessary for the analysis along. It collects data from the: measurement system; building automation system, HVAC control system and external meteorological conditions.

The monitoring system is equipped with over 400 sensors that records conditions inside and outside, weather conditions, the experimental facility. Researchers have access via the Internet to measurements being taken. The test measurement system includes the following sensors: indoor air temperature, surface temperature, radiant temperature, humidity, air velocity, heat flux, solar irradiance, luminance, CO2 concentration, sound level meter …

The building automation system includes sensors for: shading control, blind control, lighting control, open/close window control, open/close openings control,... The HVAC control system includes the following sensors: air temperature, relative humidity, air velocity, air/water temperature, air/water flow, air/water temperature flows, energy consumption of auxiliary equipment (fans, pumps). The external meteorological conditions are defined by: air temperature, humidity, solar irradiance, wind direction, wind velocity, precipitation and atmospheric pressure.

The experimentally-obtained results enable diagnoses and proposals for potential product/concept design improvements to be made and the thermal/energy performance.

The chosen measuring and management system is based on a PLC platform with Windows Embedded technology allows simultaneous scenarios analysis as well as with different requirements, boundary conditions.... The PLC layer of the control system is in charge of gathering data from the sensors and writing commands into the remote actuators, not only this but the PLC layer processes update the central database with the sensor and actuator values.

On the other hand, the Windows layer hosts the developments done in order to analyse different energy efficiency policies, e.g. will be dedicated to energy efficiency developments from a holistic approach, this means taking into account not only the potential energy demand reduction but considering, too, the storage and generation capabilities deployed in the KUBIK.

The technology used to build the energy efficiency algorithms is based on expert systems development platforms as Jess (Java Expert System Shell) and Hybrid Finite State Machines (Hybrid FSM). Both technologies are in the domain of the intelligent agent development field. The background for both technologies is that they are based on the skills to simulate complex scenarios and not only simple state transitions. Those skills are used to model scenarios in which user behaviour and preferences, outdoor and indoor conditions, altogether, are factors in order to take a decision.

CONCLUSIONS

KUBIK provides the needed support to improve the energy performance at building level, as requested by the EPBD, and in a comprehensive way, the envelope, the demand and energy generation, and based on industrialised construction systems.

The aim of this experimental facility is to offer a flexible infrastructure able to build realistic scenarios with different building components and systems, for that is compulsory to make possible the assembly and disassembly of them. This permits not only in service performance assessment but also help to develop and to evaluate assembly and erection procedures. In addition the service installations are integrated in the floor slabs, so they are accessible for repair and upgrading.

The roof and the façade of KUBIK are made of prefabricated and demountable components and can be considered as infill systems because they can change when the rest of the infill or fit-out changes, e.g. the scenario (room surface, occupancy, partition walls and the envelope components). Even though the façade might acts as a support system to include several types of windows, glassing systems, finishing…

With regard the services, the HVAC system has a clearly identified part on the support or base building, and the diffusers and other services plugging such as electrical power, water services… have a complete flexibility to be located in all the available floor lay-out and can be considered as “infill”.

REFERENCES

HABRAKEN, N.J. 1998, *The Structure of the Ordinary, Form and Control in the Built Environment*, MIT Press, Cambridge and London. United Kingdom.

VARIOUS AUTHORS. 2006, *Open building in Education*, Open House International Journal, , vol. 31 nº2.

KENDALL, S. 2008. *Education for an Open* Architecture, Proceedings of the Joint conference of CIB W104 and W110, October 20-22, 2008. College of Architecture and Planning. Ball University, Muncie, Indiana. USA.

SARJA, A. 1998. *Open and Industrialised Building*, CIB publication 222. Report of Working Commission W24. E&FN Spon, London.

VARIOUS AUTHORS. 2005-2010. *ManuBuild: Open Building Manufacturing*, collaborative research project part-funded by the EU under Framework 6, involving 25 partners from 10 countries across Europe. www.manubuild.org

Commission of the European Communities. 2008, *Directive of the European Parliament and of the Council on the Energy Performance of Buildings (recast)*. Brussels, Belgium.

VARIOUS AUTHORS, 2010, *Energy Efficient building Joint Technology Initiative, E2B JTI*. The JTI is an innovative instrument of the FP7 for supporting industrial research. It is an industry-led Public-Private Partnership (PPP) in the form of a Joint Undertaking (JU), equally funded and governed by industry and the European Commission and in some cases Member States. www.e2b-ei.eu

Fraunhofer, Institut Bauphysik, *VERU 2005– Versuchseinrichtung für Energetische und Raumklimatische Untersuchungen* http://www.bauphysik.de/veru/

OSAKA GAS Co, *NEXT 21 – Osaka Gas Experimental housing:* http://www.arch.hku.hk/~cmhui/japan/next21/next21-index.html

Authors' Addresses

José A. Chica
PhD MSc. Structural Engineer
jachica@labein.es
joseantonio.chica@tecnalia.com

Inés Apraiz
MSc. Physics

Peru Elguezabal
MSc. Structural Engineer
peru.elguezabal@tecnalia.com

Marc O. Rrips
Architect

Victor Sánchez
MSc. Structural Engineer

Borja TelladoPhD
MSc. Physics

Tecnalia, Construction Unit
Edif 700. Parque Tecnológico Bizkaia,
48160, Derio, Spain